Automated Systems for Unattended Weight and Item Monitoring at the Kurchatov Institute in Moscow, Russia

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ABSTRACT

As part of US/Russian Material Protection, Control and Accounting (MPC&A) Program, technologies that can provide unattended weight and item monitoring for stored nuclear materials have been installed at a test facility at the Kurchatov Institute in Moscow, Russia. These technologies are being evaluated by the Kurchatov technical staff to determine their potential for use in an integrated site-wide system designed to continually monitor the inventory status of stored nuclear materials at the Kurchatov Institute.

These technologies were developed and are in use at the Oak Ridge Y-12 Plant for the purpose of reducing the inventory frequency, the cost, and worker exposure associated with routine physical inventories. The technologies that have been implemented in Russia are the (Oak Ridge Systems for Enhancing Nuclear Safeguards) ORSENS™ SmartShelf™ system and the ORSENS™ capacitance weight sensors system. This paper will provide a description of the technologies, problems encountered in adapting the technology to the Russian facility, and results obtained to date from each system.

INTRODUCTION

Among the goals of the US/Russian MPC&A Program is to provide, for evaluation at Russian nuclear facilities, equipment for monitoring stored nuclear materials. To that end, two systems, the SmartShelf™ inventory system and a CAVIS capacitance weight system, developed at the Oak Ridge Y-12 Plant have been installed at the Kurchatov Institute (KI) in Moscow, Russia. Hardware (and accompanying software) sufficient to track the weight and physical location of up to 20 containers in near real time were fielded in a test bed operation at Kurchatov during 1998-1999. The technologies fielded at Kurchatov were originally developed at Oak Ridge for the purpose of reducing the cost associated with planned and emergency inventories and to reduce the level of exposure of workers to radioactive materials. They achieve these goals by continually monitoring sets of physical and assigned attributes associated with the materials under surveillance, and continually comparing them to a corresponding set of alarm limits. If any attribute value falls outside of its alarm limits, then the system raises an alarm to alert operations personnel of the excursion. Low weight readings are examples of alarms resulting from unauthorized removal of items from storage. In addition, SmartShelf™ can generate an alarm if the system's protocol for removal of an item from or placement of an item into a specified storage location is violated. In this manner, these systems decrease or eliminate the need for frequent manual inventories (because all items in their charge are under constant surveillance) and reduce worker exposure and the operational costs associated with nuclear material inventories.

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Background and System Descriptions

Historically, one of the Oak Ridge Y-12 Plant's major missions has been the storage and safeguarding of Special Nuclear Materials (SNM). Department of Energy (DOE) orders require that the status of the SNM inventories be confirmed periodically. This inventory confirmation provides assurance that the SNM is secure and has not changed. Confirmation of inventory status involves the measurement of physical characteristics of the stored material. To meet these requirements, Oak Ridge has developed several sensor systems that are capable of providing unattended monitoring of the physical and/or assigned attributes associated with stored nuclear materials. These systems include the Continuous Automated Vault Inventory System (CAVIS™), SmartShelf™, and the ReflectoActive Seal System™. Two of these technologies were installed at KI for evaluation by the Russian staff on their materials stored in their environments. These technologies are the CAVIS™ capacitance weight sensor system and the SmartShelf™ inventory tracking system.

CAVIS Weight Sensor

The capacitance weight sensor can monitor inexpensively, for long periods of time and in widely variable environments, the weight and temperature of stored nuclear material. The capacitance weight pad consists of two stainless steel plates separated by load bearing springs and a differential capacitance proximity detector (shown in Figure 1). As weight is applied to the unit, the springs compress and the top plate moves closer to the proximity detector. This plate movement changes the duty-cycle of the on-board oscillator, which change corresponds directly to the change in item weight. Weight information is combined with temperature information and sent back to the system in a low-noise time-domain format. A single coaxial cable is used for power and signal, simplifying facility wiring.

The novel proximity probe uses a differential capacitance configuration that compensates for atmospheric humidity and temperature without the need for a sealed housing. All the electronics in the weight pad are radiation-resistant solid state devices that are expected to withstand a radiation dose of 10^5 R.

The unique modular design of the capacitance weight pad allows it to be customized for different size containers and different weight loads. The open frame design accommodates a variety of radiation detectors that can be installed in the weight pad without significant modifications to the pad.

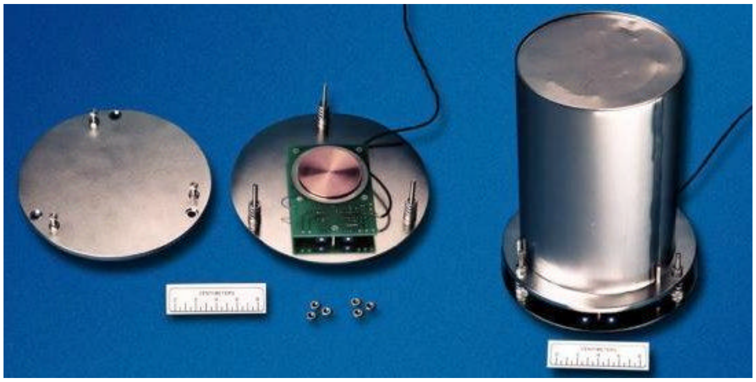

Figure 1: CAVIS Weight Pad

SmartShelf™

SmartShelf™ is a hardware and software system for asset management applications which is illustrated in Figure 2. The SmartShelf™ system necessary to know the physical location of controlled items at all times. It has been designed for rapid record keeping in dynamic storage environments (environments where items are frequently moved or removed from storage locations). The system provides an inexpensive method for maintaining 100%, 24-hour surveillance on all stored items and/or facility assets. Reports of current inventory, employee activity, access to particular assets, or any other system feature are available in minutes and on demand. SmartShelf™ provides the who, what, when, and where of asset management.

SmartShelf™ keeps track of controlled items via electronic buttons attached by the user to the items. Attachment may be effected by adhesives, straps, spot welding, or by the use of specially designed retainer plates. Buttons are 16 mm in diameter, 5 mm high, made from stainless steel and house an electronic integrated circuit that is laser-engraved at the time of fabrication with a permanent unique serial number. Authorized personnel are issued identification buttons by which they make themselves known to the system when accessing controlled items. Each controlled item is electronically connected to a SmartShelf™ node for surveillance. Nodes are chained together, and up to eight chains, connecting hundreds of nodes, may be connected to a node computer (the gray rectangular box in the center of Figure 2). Several node computers can be daisy chained together and connected to a central (desktop personal) computer running Microsoft® Access. In this way thousands of nodes and controlled items may be monitored from a single central site.

Figure 2: The SmartShelf System Depicting Container Button Attachment

SmartShelf™ continuously monitors itself to verify the presence of its nodes. Alarms are raised if nodes are lost or disabled. Each node is also queried to determine if a controlled item has been attached or removed. During the access protocol, an authorized operator is required to present his or her identification button to the system, and if this is not done according to the protocol, an alarm is raised. SmartShelf™ has been designed to be robust in the face of loss of parts of the system. The central computer can raise an alarm when it detects that a node computer has failed, but will continue to monitor other working node computers. Similarly, should the central computer fail, the node computers will continue their surveillance and simply store records of activity in local memory until the central computer is restored. Discrepancies between the expected inventory and actual inventory are resolved when the restored hardware becomes operational. Microsoft® Access® stores all of the information associated with activity from SmartShelf™ nodes. The database can be queried to determine the frequency of access by personnel, the current inventory, the status of any item, or any other attribute. New queries and reports can be designed with ease by the end user familiar with Access. SmartShelf™ systems have been deployed at Oak Ridge, and at the All-Russian Scientific Research Institute of Experimental Physics (VNIIEF) in Sarov, Russia, and are under evaluation at the Kurchatov Institute in Moscow, Russia.

Testing at the Kurchatov Institute

A test bed facility was set up in Building 135 at the Kurchatov Institute. Twenty containers were selected for evaluation; because the Kurchatov containers are significantly different than those for which the weight sensors were originally developed, a modification was required. The Kurchatov containers measure about cm across and are about cm high. Thus it was necessary to retrofit the original designs to accommodate the Kurchatov containers.

Adapter plates to fit the smaller containers, as shown in Figure 3, were fabricated in the U.S. to Russian specifications and shipped with the weight sensors. These plates are designed to fit over the upper plate of the weight sensor and center the item on the weight pad. The springs on the original Oak Ridge weight pad were also changed to accommodate the lower weight range of the KI materials. These were the only modifications that were required from the original Oak Ridge System.

The following is a summary of facts accumulated by KI staff during the evaluation of the Oak Ridge automated systems for unattended weight and item monitoring.

1) Both the Weight Sensor system and the SmartShelf™ system were installed for long-term operational evaluation in one of the fresh fuel storage areas of Building 135 at the 'Kurchatov Institute' Russian Research Center. This installation was completed in September 1998.

2) Both systems were assigned for unattended weight and item monitoring of highly attractive fresh nuclear material. Nuclear material in a form of cylindrical rods with diameter 2 mm and length 100 mm, manufactured from hard uranium-carbide solution and carbides of metals with high melting point and enriched to about 90% of U-235, are stored in the KI containers. Each container contains about 1 kg of U-235. The material is accounted for as a material in a semi-bulk form. Average number of fuel rods in one container is about 1000. The total number of containers is 20. Due to nuclear safety regulations, containers are located in two metal safe cabinets each of which contains ten containers positioned no more than five per cabinet - two containers per shelf.

3) The weight range of the containers including nuclear material, cover, and seals is within the range 2.3-3.2 kg. Average weight of the container with nuclear material is about 3 kg.

4) The Oak Ridge weight sensors were calibrated in accordance with operating manuals. Results of calibration show that the readings for different weight sensors with weight load 1 kg and 3.3 kg are within (189.2 - 190.4) microseconds and (274.7 - 276.8) microseconds. It was noticed that certain improvement of both the calibration procedure and the weight sensors design may be achieved by introduction of some quantitative (numeric) independent control over position (angle of turn) of the copper nuts fixing the springs, and plugs for potentiometers.

5) Since September 1998 the Weight Sensor system has been in operation. The system operation has been very stable.

6) The CAVIS software was analyzed. The analysis showed that the output pulse width in microseconds is transferred into weight in grams with help of the following interpolation polynomial of the third order:

$$p = a+bs+c(s*s)+d(s*s*s)$$

where:
'p' is weight (in grams);
's' is output pulse width (microseconds);
'a' is a constant -7.3040;
'b' is 866.145;
'c' is 3.3284;
'd' is 0.00043.

Implementation of this polynomial with original recommended coefficients stated above lead to measurement errors in container weight data. The half-width of 90% confidence interval for measurement error is about 300 gram. The KI staff calculated new coefficients that decrease the measurement error from 300 to 50 grams. However, the KI staff correctly indicated that if each weight sensor was provided with its own polynomial with appropriate coefficients the measurement error might be decreased to about 20 grams.

Editorial Note: Oak Ridge does not use this algorithm for the weight calculation. Another algorithm was also sent with the weight sensor system to the KI. It was incorporated into a LabVIEW program that uses a curve fit method instead of direct calibration coefficients for each weight sensor. The LabVIEW version of the software converts the pulse width readings into weight readings using the following equation.

$$W = W_0 - A/(t_0 - t)$$

Where:

W is the calculated weight in grams.

W_0 is a constant.

A is a constant.

t_0 is a constant.

t is the measured pulse width in seconds.

This equation was derived from an analysis of the weight pad design. For a set of eight measurements, it provides a significantly better fit than the polynomial described above. KI staff will be advised of this feature.

7) A 20-unit SmartShelf™ system was also delivered to the KI; the system was tested, adjusted, and installed in accordance with operating manuals. However, the installation of the SmartShelf™ system discovered a very specific software problem related to presentation of dates in different software packages. So-called 'localized' versions of operating systems and other system software packages may have differences in presentation of dates in comparison with the standard US English versions. Such differences were not evaluated in advance thus preventing operation of the SmartShelf™ system. The Oak Ridge staff conducted an intensive investigation of the problem, discovered the cause, and provided a fix. Since February 1999 the SmartShelf™ system has been in operation in parallel with the Oak Ridge weight sensor system.

Evaluation of the SmartShelf™ system performance under various operating conditions is still continuing.

Figure 3: The System Installation in Building 135 at the Kurchatov Institute

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CONCLUSIONS

Initial operating experience with capacitance weight sensors has demonstrated that equipment designed for materials in the US often require modification for offshore implementation. Differences in the design and size of containers were found to require some minor mechanical modifications to the weight sensors. The SmartShelf™ equipment functioned properly after some date-time format corrections (US formats vs. European formats) were made in the database.

The main goal of these trial operations is to evaluate the possibilities for integration of these systems with the KI site-wide computerized material accounting and control system currently deployed at 14 nuclear facilities. Taking into consideration the cost of the physical inventory process, the number of nuclear facilities, and the follow-on physical inventory verifications, the implementation of these systems for unattended weight and item monitoring, is considered by the KI staff, as a very cost-effective and promising approach.